Dendrophobia in bonobo comprehension of spoken English

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The Dendrophilia hypothesis

> 'Humans have a multi-domain capacity and proclivity to infer tree structures from strings, to a degree that is difficult or impossible for most non-human animal species.' (Fitch 2014: 352)

- Compare the 'recursion-only' hypothesis associated with Hauser, Chomsky & Fitch (2002) (that recursive computation is unique to humans and unique to language):
  - Recursion-only hypothesis is absolute and domain-specific.
  - Dendrophilia hypothesis is relative and domain-general.
- Both invite comparisons (between species, between domains).
- This talk: comparison of grammar induction by a human infant and a bonobo in a naturalistic setting.

The Kanzi corpus

- Savage-Rumbaugh et al. (1993): parallel corpora of 660 instructions directed to Kanzi (a bonobo) and Alia (a human infant), and description of their responses.
- A subset of these utterances (involving NP-coordination) require hierarchical phrase structure for correct interpretation.
- Kanzi fails to interpret those utterances correctly, while Alia has no problem.
- This supports the Dendrophilia hypothesis, from a different perspective from artificial grammar learning studies (e.g. Fitch & Hauser 2004 on $(ab)^n$ vs. $a^n b^n$).
- However, other acquisition studies suggest that human infants are usually slow to acquire NP-coordination.
- They get there in the end, though. Kanzi never got there.
- Humans aren't usually Dendrophiles, but Kanzi is a dendrophobe.

Roadmap

1. $(ab)^n$ / $a^n b^n$ review
2. Kanzi/Alia data
3. Other acquisition studies
4. Conclusion

Section 1

Artificial Grammar Learning studies

Fitch & Hauser's tamarins

- Fitch & Hauser (2004) tested the ability of humans and cotton-top tamarins to learn to recognize two patterns:
  1. $(ab)^n$
  2. $a^n b^n$
- Humans could learn both; cotton-top tamarins only learned $(ab)^n$.
- Many studies have disputed this result on empirical grounds or refined its interpretation.
- I'm going to make a different argument (see also Rogers & Pullum 2011, Jäger & Rogers 2012): even if the result stands, it doesn't tell us much about Dendrophilia.

Why $(ab)^n$ and $a^n b^n$?

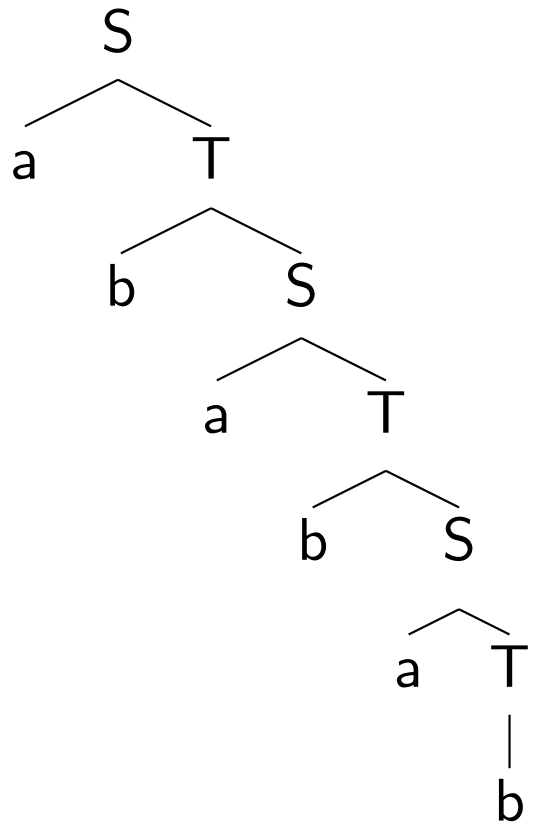
- $(ab)^n$ and $a^n b^n$ differ in expressive power needed to recognize them.
- $(ab)^n$ can be recognized by a regular grammar; $a^n b^n$ can't.
- Original Chomsky hierarchy:

  Regular $\subset$ Context-free $\subset$ Context-sensitive $\subset$ Unrestricted

- $a^n b^n$ can be recognized by a context-free grammar.
- CFGs are also adequate for capturing most grammatical phenomena in most languages.
- So the result from Fitch & Hauser (2004) sounds significant.

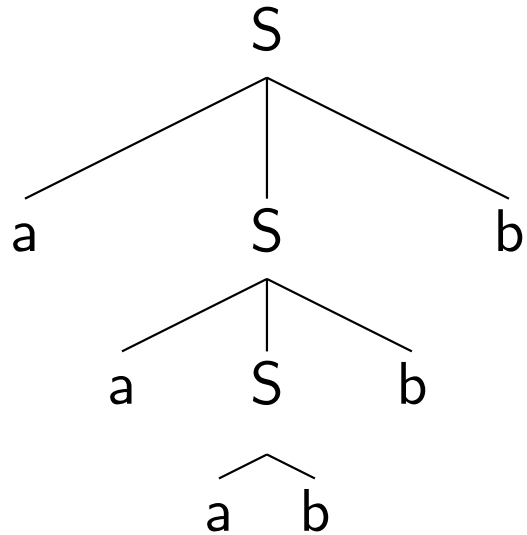
Regular grammar for $(ab)^n$

1. $S \to aT$
2. $T \to bS$
3. $T \to b$



Context-free grammar for $a^n b^n$

1. $S \to aSb$
2. $S \to ab$



Strictly local stringsets and regular grammars

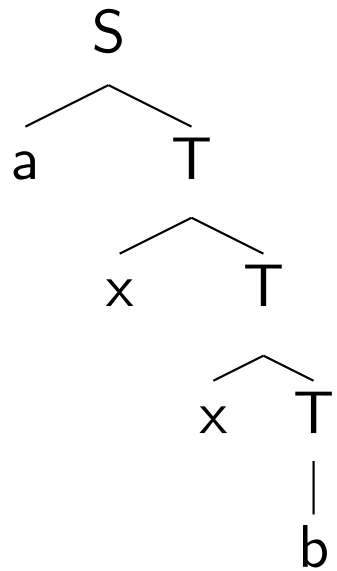
- Rogers & Pullum (2011): $(ab)^n$ is strictly 2-local. Just check every bigram is in this set:

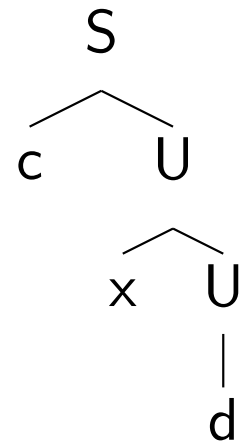
$$\{\langle START, a\rangle, \langle a, b\rangle, \langle b, a\rangle, \langle b, END\rangle\}$$

- Strictly local stringsets are a proper subset of regular grammars. E.g. regular grammars can contain finite amounts of nonlocal dependencies.

Nonlocal dependencies in regular grammars

1. $S \to aT$
2. $T \to xT$
3. $T \to b$
4. $S \to cU$
5. $U \to xU$
6. $U \to d$

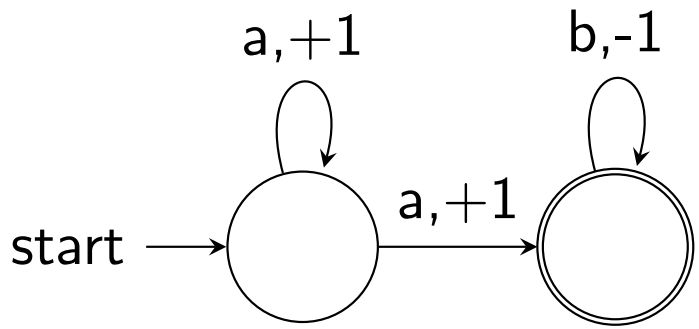




Counter grammars and CFGs

- $a^n b^n$ can be recognized by a counter grammar, which is like a CFG with a single nonterminal symbol.
- To parse a CFG, you have to keep track of which kinds of phrases you're in the middle of.
- With a counter grammar, you just keep track of how many phrases you're in the middle of.

A counter automaton for $a^n b^n$



- $+1 =$ 'write an arbitrary symbol to the tape.'
- $-1 =$ 'delete an arbitrary symbol from the tape.'
- Stop when the tape is blank.

Time for a crisis

- Counter grammars have little to do with natural language (a major domain of inquiry for the Dendrophilia hypothesis).
- Hard to draw inferences about ability to learn hierarchically structured representations from $a^n b^n$.
- (Concrete consequence: noun phrases are structurally distinct from verb phrases, but both allow recursive embedding, and you can't represent that with a counter grammar).
- So we should look elsewhere for data pertaining to the Dendrophilia hypothesis.

Section 2

The Kanzi corpus

Corpus structure

- 660 utterances each for Kanzi and Alia.
- Each has this format:

  287. (C) *Kanzi, take the tomato to the colony room.* (Kanzi makes a sound like "orange"; he then takes both the tomato and the orange to the colony room.) [C is scored because it is assumed that Kanzi is announcing that he wants to take an orange and have it to eat.]

  - 287: item number
  - (C): code (C, C1–C5: correct; others: incorrect in various ways)
  - *Kanzi, take the tomato . . .*: utterance
  - (Kanzi makes a sound like "orange" . . .): description of response
  - [C is scored because . . .]: justification of code

What Kanzi gets right

- Savage-Rumbaugh et al.: Kanzi responds correctly 71.5% of the time (Alia: 66.6%).
- For 420/660 trials, a 'semantic soup' strategy would give a correct response.
  - This includes examples like *Show me the hot water*, or *Get the lighter that's in the bedroom*, where a standard English grammar would have an internally complex NP.
- Kanzi is also fine on 43 'reversible ditransitive' pairs (76.7% correct, one example repeated).

  525. (C) *Put the tomato in the oil.* (Kanzi does so.)
  528. (C) *Put some oil in the tomato.* (Kanzi picks up the liquid Baby Magic oil and pours it in a bowl with the tomato.)

This requires sensitivity to linear order, a step beyond semantic soup.

Coordinate structures

- In simple cases, there's a 1–1 mapping between nouns and NPs.
- Kanzi arguably interprets the noun rather than the full NP.
- That leads to trouble with coordinate NP objects.

  Fetch the ball and the rock.

  Which noun describes the patient of *fetch*? And what's the other noun doing there?
  - Same problem arises in principle with *Get the lighter that's in the bedroom*, only lighters are much easier to get than bedrooms.
- 'Standard English' solution: *the ball and the rock* is a complex constituent, part of a hierarchical representation of phrase structure.
- Kanzi hasn't found that solution.

Kanzi's responses

- Ignore first noun: 9/18 trials.

  428. (PC) *Give the water and the doggie to Rose.* (Kanzi picks up the dog and hands it to Rose.)

- Ignore second noun: 5/18 trials.

  526. (PC) *Give the lighter and the shoe to Rose.* (Kanzi hands Rose the lighter, then points to some food in a bowl in the array that he would like to have to eat.)

- Respond correctly: 4/18 trials (22.2%; Alia 68.4%)

  281. (C) *Give me the milk and the lighter.* (Kanzi does so.)

- This represents a species-specific deficit (Fisher exact test, $p = 0.008$), and a construction-specific deficit (binomial test, $p = 1.1 \times 10^{-5}$).

Section 3

Acquisition studies

Gertner & Fisher's gorping

- Gertner & Fisher (2012): show 21-month-olds parallel videos of coordinated actions (boy and girl act independently) and transitive actions (boy acts on girl), and play one of:
  1. The boy is gorping the girl!
  2. The boy and the girl are gorping!
  3. The girl and the boy are gorping!
- Subjects look more to the transitive for both (1) and (2).
- Conclusion: 21-month-olds use linear order of nouns to determine who the agent is.
- They don't automatically represent *the boy and the girl* as a structurally complex subject.
- But they can be encouraged to (*Oh yes, they are gorping*, Arunachalam, Escovar, Hansen & Waxman 2011), and they slowly learn to over coming months (e.g. Hirsh-Pasek & Golinkoff 1996).
- This is not dendrophile behaviour. But humans are not dendrophobes.
- Kanzi is.

Conclusion

- There are serious obstacles to interpreting results like Fitch & Hauser (2004) as evidence supporting the Dendrophilia hypothesis.
- But the evidence from the Kanzi corpus broadly supports that conclusion.
- Alia has no trouble with hierarchical phrase structure; Kanzi performs roughly at chance.
- We can see this because of evidence about interpretation, not just string recognition.
- We can infer aspects of interpretation from behaviour, and aspects of grammatical representation from interpretation.
- Nevertheless, acquisition studies suggest that human infants are not quick to represent coordinate NPs as hierarchically structured.
- In other words, we are not dendrophiles, but Kanzi is a dendrophobe.

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